# Multi-Channel Transcutaneous Cortical Stimulation System

Contract # N01-NS-7-2365

Progress Report #18

for the contract period 7/1/01 – 9/30/01

Illinois Institute of Technology

Principal Investigator: Philip R. Troyk, Ph.D.

The goal of this project is the design, fabrication, and testing of a ***Multi-Channel Transcutaneous Cortical Stimulation System*** to be used in a prototype artificial vision system**.** This is the eighteenth progress report for this project. In this report we include a condensed version of a poster presented at the 2001 neural prosthesis workshop. This poster provides details of our collaborative effort, funded elsewhere, in which the technology developed under this contract is being used.

**Introduction**

The development of an implantable human cortical visual prosthesis has been a goal of neuroprosthesis research for 30 years. During this time, the NIH has funded numerous intramural and extramural studies to advance fundamental technologies and address biological questions necessary for the design and fabrication of an implantable system to stimulate the primary visual cortex with intracortical microelectrodes. However, long-term demonstration of the stability of implanted microelectrodes, the integration of electrodes into reliable, interconnected multichannel arrays, fabrication of implantable multichannel stimulators, and fundamental visual science studies researching strategies for neural coding are currently lacking.

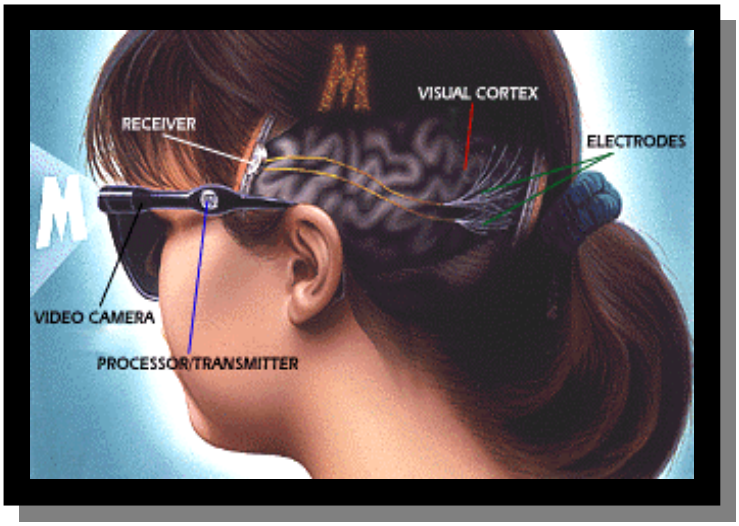
Our long-term goal is to develop an implantable system which will provide vision for a large population of persons with blindness. To accomplish this, a multi-institutional project team is engaged in a program to research the intra-cortical visual prosthesis. This team includes investigators from 4 institutions, plus consultants with experience from the NIH, and the Laboratory of Neural Control intramural visual prosthesis project. The team institutions and personal are organized as follows:


<u>Illinois Institute of Technology, Chicago, IL</u>
Philip Troyk, Ph. D., P.I., Technology/Experimental Design
<u>EIC Laboratories, Inc., Norwood, MA</u>
Stuart Cogan, Sc. D., Electrode Electrochemisty and Design
<u>Huntington Medical Research Institute, Pasadena, CA</u>
William Agnew, Ph. D., Histological Analysis
Leo Bullara, B.A., Electrode Array Design
Doug McCreery, Ph. D., Electrode Design/Safe Stimulation
Ted G. H. Yuen, Histological Analysis
<u>Laboratory of Neural Control Affiliated Researchers</u>
Martin Bak, B.S., Electrode Design and Fabrication
Conrad Kufta, M.D., Neurosurgery
Edward Schmidt, Ph. D., Neurocontrol/Electrophysiology
<u>University of Chicago, Chicago, IL</u>
David Bradley, Ph. D., Primate Testing, Visual Science
Robert Erickson, M.D., Neurosurgery
Vernon L. Towle, Ph. D., Cortical Imaging/Surgical Design
<u>Consultants</u>
Barry Richmond, M.D., NIH, Visual Science
Edgar Deyoe, Ph.D., Med College of Wisconsin, Visual Science

**Intra-cortical Stimulation of Visual Cortex**

Restoration of vision, using a neuroprosthesis, depends upon providing the cortex with a well-controlled temporospatial electrical stimulation pattern that mimics the pattern of neural activity normally associated with vision, or uses the natural tuning properties of the visual system, to provide the cortex with meaningful sensory input. Restoring vision presents a technical challenge because it is likely that a large number, at least hundreds, of parallel channels of stimulation are required. This project seeks to understand the stimulation of the primary visual cortex (area V1) using a large number of intracortical microelectrodes.

The concept of a cortical visual prosthesis is based on the fact that localized electrical stimulation of the human visual cortex can excite topographically mapped visual percepts called phosphenes, as demonstrated by Penfield in the 1940's. Inspiring experiments by Brindley, and others in the 1970's studied the effects of visual cortical stimulation with relatively large electrodes placed on the pia-arachnoid surface, and resulted in multiple non-contiguous phosphenes, with uncomfortably high stimulus currents, that produced occasional elicitation of pain due to meningeal or scalp stimulation.

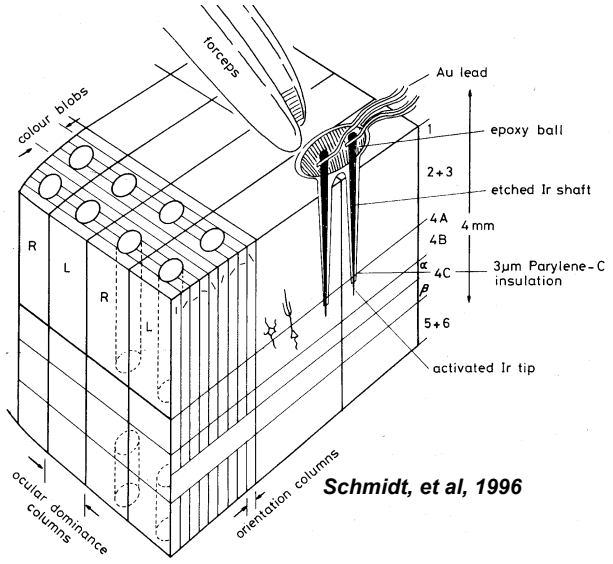


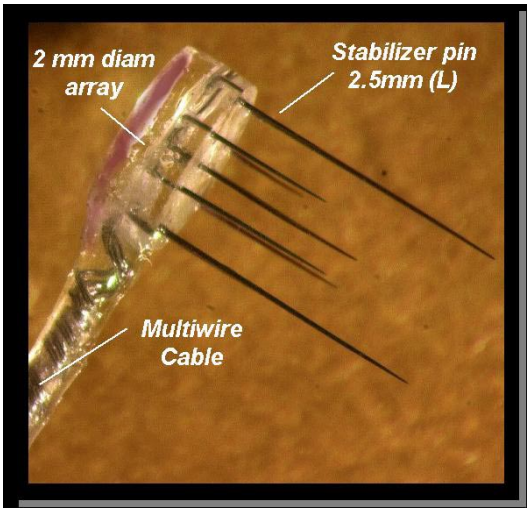

By implanting microelectrodes within the visual cortex, with exposed tip sizes of the same order of magnitude as the neurons to be excited, much more selective stimulation, at lower stimulus currents, can, in principle, be achieved, resulting in more precise control of neuronal function. Studies of intracortical stimulation were initiated at Huntington Medical Research Institute (HMRI), in 1979, in which the feasibility of safe, chronic, intracortical stimulation of the cortex was established. Starting in 1983, work by Brummer, and subsequent work by Robblee, Rose, Cogan, and others at EIC Laboratories eventually resulted in microelectrodes made from activated iridium. Implantation of 38 micro-electrodes in a human volunteer, at NIH, in 1994, provided the motivation for the development of a fully implantable 1024-channel transcutaneous cortical stimulation system by the Illinois Institute of Technology (IIT).

**Intra-cortical Electrodes**

In order to implant multiple electrodes in the cortex such that electrode packing density will be sufficiently high, electrode design and associated insertion methods need to be sophisticated beyond those commonly used for placing small numbers of individual electrodes.

The electrode tile approach, designed by HMRI, uses arrays of 8 electrodes with outside dimensions on the order of 2mm. Many arrays would be used as tiles, covering the cortical V1 area. Using a custom inserter to rapidly insert the arrays, at speeds up to 1m/sec, bleeding is minimized *even if penetrating blood vessels*. In between the tiles, and near complex vasculature, single or dual NIH-type electrodes would be used. Electrodes are 35µm-diam iridium shanks with Parylene-C insulation.




***Intra-cortical Electrodes - left NIH design, right HMRI array***

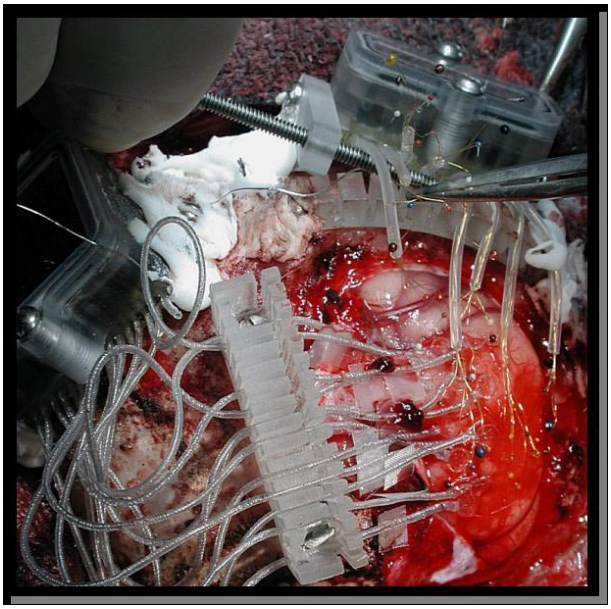
**Implantation**

During August of 2001, our team implanted 152 intra-cortical electrodes in the primary visual cortex of a macaque. This study was designed as a first step in our efforts to explore the technical and experimental problems associated with our project goals. In particular, we are investigating the feasibility of:

* Surgically implanting large numbers of electrodes in a chronic animal;
* Providing, and maintaining direct electrical connection to every electrode;
* Using a common electrode design for long-term stimulating and recording;
* Devising the laboratory procedures and data collection techniques required to study large numbers of parallel cortical interfaces;
* Using an animal behavioral model to understand artificial activation of cortical neuronal networks.

In preparation for the complex surgical procedure, a plastic model of the animal's skull, enclosing a silicone brain model were fabricated from CT scan files, and were used to plan the placement of the electrode connectors and to practice routing of lead wires.

We planned to implant 192 electrodes in 24 groups of 8. 16 HMRI electrode arrays, and 64 NIH single electrodes were fabricated. The electrodes have activated iridium-oxide tips with laser-exposed areas of 500 $\mu m^2$ (HMRI) and 200 $\mu m^2$ (NIH), chosen as a comprise between the need for selective neural recording and maintaining safe stimulation charge density. Attrition of electrodes and connector contacts during fabrication of the arrays and connector housings, as well as during surgery, resulted in 152 electrodes being implanted. The surgical procedure spaned 8-1/2 hours, with our lead surgeon, Dr. Erickson working with Drs. McCreery, Kufta, and Marty Bak to accomplish the craniotomy, mount the hardware, and implant the electrodes. Approximately 12 individuals assisted at various times during the procedure. After closure of the dura and skull, a liquid acrylic skull cap was cast in place, covering all wires and supporting hardware.

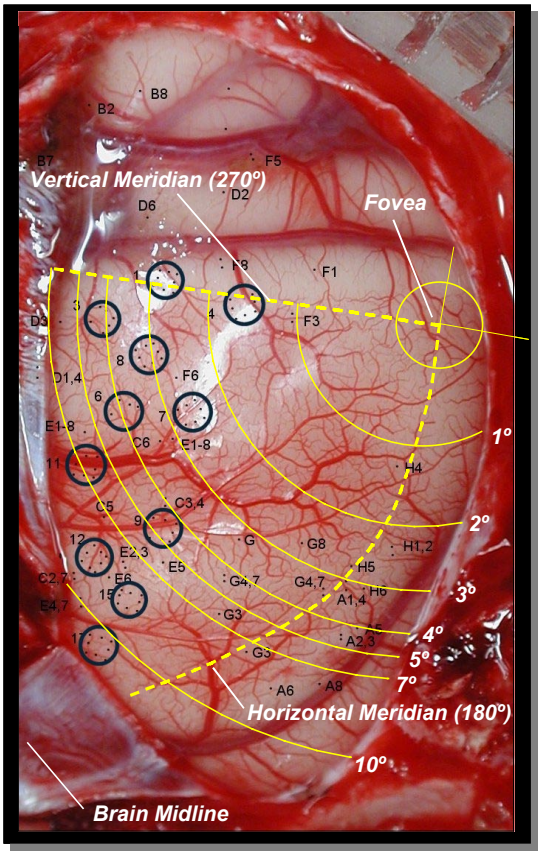


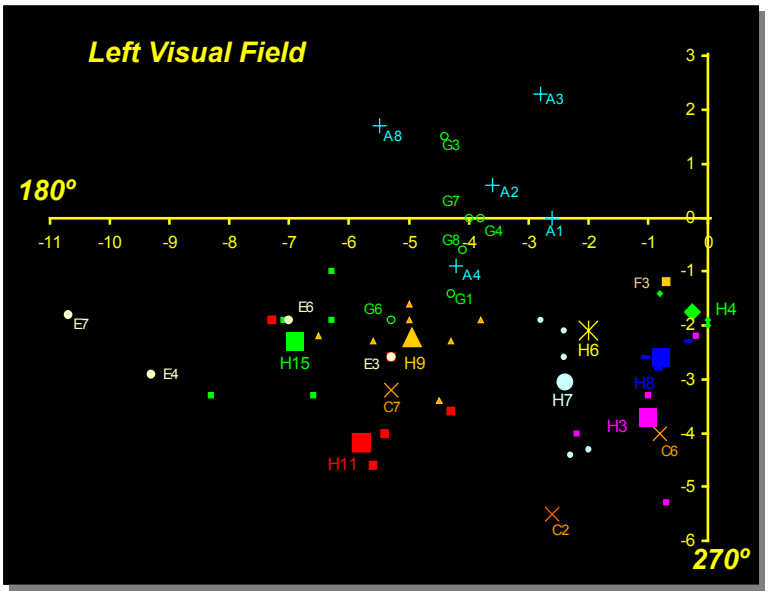
**Post-Surgical Testing**

A post-surgical two-week recovery period was allowed. During this time, wound healing was monitored, and minor mechanical problems related to the acrylic skull cap and connector housings were resolved. The connector housings were designed with an O-ring gasket on the covers to prevent any external fluid from leaking into the housings and corroding the connectors. Some initial modifications to the covers and gaskets were required to insure integrity of the seals.

Following the recovery period, each contact of the connectors was tested for continuity to an electrode. Each contact was connected to a constant current driver comprised of a Block Chip that was controlled by a computer interface. The electrodes were driven with a biphasic, cathodal-first, 200μsec/phase, 10μA, 30Hz pulse train. The voltage waveform was captured on a virtual instrument computer-based oscilloscope and stored. A contact was judged as being connected to an electrode if the voltage waveform showed the typical features of an access resistance and capacitive interface. Open contacts were clearly identifiable. We identified 114 electrodes for which we have electrical connection. The remaining 38 electrodes are ones that had known connection problems prior to, or during the surgery. In no case did a connection to an electrode deteriorate following the surgery. We used high-resolution digital photographs, taken during surgery, to identify the physical location of each electrode on area V1. During the past 4 weeks,

we have made preliminary measurements of receptive fields using a manual mapping method while recording from the electrodes using a 96-channel computer-based neural recording system.




62 electrodes were found to produce measurable cortical signals. These receptive fields have been correlated to published retinotopic maps, for the macaque, and a crude, but topologically consistent, retinotopic map was constructed.

On the retinotopic map, above, the HMRI array locations are indicated by numbered circles, with dots within each circle that represent the individual electrodes. The NIH electrodes are indicated by letters A-H, for 8 electrode groups, with the numerical suffix identifying the electrode within each 8-electrode group. The retinotopic map was created by using the receptive field data shown above (left). Measurement error, inherent to a manual field mapping method was compensated for by averaging the field center locations for the electrodes within individual HMRI arrays, and creating an central field location, indicated by large markers, for each array.

**Stimulation**

We are at the very initial stages of stimulation studies. We intend to use the retinotopic mapping as the basis for establishing a reward-based task in which the animal makes saccades to locations of visual stimuli. The visual stimuli will be replaced by electrical stimulation and the animals saccade response recorded. In the next report we will describe the electrical driving conditions of the electrodes, in terms of impedance and voltage response to stimuli produced by our laboratory stimulation system, described in our last progress report.